THE DESTRUCTION OF WOOD BY FUNGI

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Millions of tons of wood are produced every year in the forests of the world. Observation, however, tells us that the sum-total of wood upon the surface of the earth remains fairly constant from year to year and from century to century. We must conclude, therefore, that there are destructive agencies at work by which millions of tons of wood are destroyed annually. Regarded in this light the problem of what these destructive agencies are, and how they act, becomes of general scientific and economic interest.

The balance between the amount of wood formed by trees and that destroyed in a given period of time, such as a century, has not always been kept. An excess in production over destruction led to the formation of the Coal Measures. There is no reason to suppose that the assimilatory activity of trees during the Carboniferous Period was materially greater than now, if similar climates be taken into account. The accumulation of wood seems to have been due to the geological conditions having been unfavourable to the destructive agencies, and in particular to fungi. The dead parts of trees, which are deposited on the floors of most forests at the present day, are kept constantly moist or wet, so that the cell-walls contain imbibed water, whilst the cell-lumina are chiefly filled with air. Under these conditions the wood-destroying fungi flourish, and cause even the giants of the forest to rot and disappear within a comparatively few years after death. The exact manner in which coal accumulated during the Carboniferous Period has been a matter of dispute, but there can be no doubt that the forest trees grew for the most part in low-lying, swampy regions. Palæobotanists have also found fungus hyphæ in fossil wood, so that it seems probable that wood-destroying fungi were quite common in those early times. Possibly some day the fruit-bodies of Fomes or other species of Polyporei, attached to tree-trunks, will be discovered, but so far nothing of the kind has

been brought to light. The fallen leaves, twigs, branches, and tree-trunks of the Coal Measure forests seem to have been quickly plunged into free water, and thus to have become thoroughly soaked. They further appear to have been carried by streams into salt lagoons [1] or lakes, and there to have been finally deposited. At the present day such conditions are found to be very unfavourable to the wood-destroying fungi. The mycelium of these organisms does not seem able to develop in wood which has its cell-lumina filled with free water. Wooden piles, submerged beneath either fresh or salt water, remain long, if not entirely, protected from fungi. Thus the piles in the lake dwellings of Switzerland and Ireland have lasted for centuries. When the piles of Old London Bridge [2] were taken up they were found to be sound after six hundred and fifty years of use. Complete saturation of wood with water, which now preserves timber from the inroads of fungi, was in all probability just as unfavourable to these organisms in the Carboniferous Period. When this is admitted it is easier to understand the accumulation of the materials which have formed the coal seams.

Among the agents at present at work in destroying wood, animals will first be shortly considered. When compared with plants, however, they play but a subordinate part in the great process.

Almost all the higher animals leave wood untouched, if for no other reason, because its mechanical resistance defies their teeth. A few rodents have the habit of gnawing wood, partly for the purpose of making burrows in which to live or hide, and partly in order to obtain food. The enormous annual destruction of wood, including standing timber, by fire through the agency of man is, of course, a matter of common knowledge. Charred wood, found by palæobotanists in rocks which were formed before man had been evolved, indicates that forest fires have originated in the past by lightning or spontaneous combustion.

Certain Crustacea of the group Malacostraca, e.g. *Chelura terebrans*,[3] bore into wood piles and thus weaken them. Some Molluscs of the group Lamellibranchiata, e.g. *Teredo navalis*, the "ship-worm," have the same habit. By boring into piles the

[1] Geikie, *Text-book of Geology*, 3rd ed., p. 805.
[2] G. S. Boulger, *Wood*, 1902, p. 254.
[3] R. Hertwig, *Lehrbuch d. Zoologie*, 4te Aufl. p. 386.

animal has been the cause of the breaking of certain dams in Holland,[1] with the loss of many human lives.

It is well known that many insects bore into wood. According to Drummond,[2] in certain parts of tropical Africa not a stick falls to the ground but is immediately converted into powder by the activity of the Termites or White Ants. The true Ants, too, sometimes make their living-rooms in wood.

Numerous species of Coleoptera inhabit wood. One of the best known is *Anobium striatum*, which often destroys furniture, in which it bores circular holes. This insect flourishes in air-dry timber, where it is practically free from all competitors. No fungus could grow under such conditions. It seems probable that *Anobium* and its allies obtain the water necessary for the structure of their tissues by splitting up carbohydrates such as cellulose and starch. The beetles live upon the wood into which they bore. The exact manner in which they act upon the lignified membranes still requires elucidation, but doubtless they digest the starch and protoplasm contained in the medullary rays and wood parenchyma by acting upon them with appropriate enzymes.

We may now consider the vegetable organisms which destroy wood. Bacteria are the cause of the breaking down of so many organic substances that it might well be expected that they are also concerned in the destruction of wood. As yet, however, no wood-destroying bacteria have been isolated. Bacteria which destroy unlignified membranes, consisting of cellulose, are very wide-spread in nature, and, as Omelianski[3] has shown, can be obtained from any soil containing humus, or pond where vegetable matter is decomposing. Nevertheless, when cellulose cell-walls have become lignified, they long resist the action of bacteria. These organisms are unable to penetrate into solid wood, and thus have little chance to act upon it until, owing to the attacks of fungi, it has reached the last stages of destruction.

The chief agency at work in destroying wood is undoubtedly the Fungi. Of these the groups concerned are the Ascomycetes and the Basidiomycetes.

In order to clear the way for subsequent remarks, it may be

[1] R. Hertwig, *loc. cit.* p. 328 ; *vide* also Hedley, *Austral. Ass. Adv. Sci.* 1901, p. 237.

[2] H. Drummond, *Tropical Africa.*

[3] Omelianski, *Ref. in Chem. Centralbl.* 1898, Bd. I. p. 269

stated that every wood-destroying fungus consists of two parts, a vegetative and a reproductive. The vegetative is known as the *mycelium*, which is very much branched and made up of very fine threads or *hyphæ*. These penetrate in all directions into the cells of the wood and cause it to go rotten. Such decayed wood is often known popularly as "touchwood." The reproductive part of the fungus develops on the outside of the rotting wood. It is known as a sporophore, or *fruit-body*. It is devoted exclusively to the production and liberation of spores, and is developed entirely at the expense of the food obtained by the mycelium hidden in the wood. Some fruit-bodies are very large and form brackets or hoof-shaped masses of various hues. When projecting from tree-trunks or logs they may attract the attention of the least observant.

The Ascomycetes rarely do much damage to the wood in bulk, such as tree-trunks or thick branches. They are numerous, however, upon twigs and the surface of wood. They require a comparatively small amount of food to produce their small fruit-bodies.

The Basidiomycetes are the most active destroyers of wood. The lower forms have comparatively simple fruit-bodies, and are often found on small branches. The higher forms, however, have more complex and, as a rule, much more massive fruit-bodies. When wood is the food, this is obtained by acting with enzymes upon the substance of thick branches and tree-trunks. In this manner the Basidiomycetes remove most of the wood which falls to the floor of our forests.

It is admitted that if timber be kept perfectly dry, or submerged beneath water, it will resist decay for an indefinite period. It was formerly thought that alternate exposure to air and water was sufficient *per se* to bring about the decay of wood. There is, however, no evidence that such is the case in the absence of living organisms.

The causes which lead to the decay of wood were elucidated toward the latter end of the nineteenth century. Just three decades have passed since the publication of Robert Hartig's classical researches.

Theodore Hartig,[1] father of Robert Hartig and the discoverer of sieve-tubes and aleurone grains, was the first to investigate the destruction of wood by fungi in a scientific manner, and

[1] T. Hartig, Berlin.

he published the results of his work in 1833 in a paper entitled "Abhandlung über die Verwandlung der polycotyledonischen Pflanzenzelle in Pilz- und Schwamm-Gebilde und der daraus hervorgehenden sogenannten Fäulniss des Holzes." Hartig's views of the Red Rot of trees were as follows: As a tree passes a certain age the functions of its parts begin to be lost, bringing about the decay of the wood. This, however, may happen earlier, in consequence of unfavourable external conditions. The first step in decay is the breaking up of the contents or membranes of the wood-cells into tiny balls or monads. These monads gradually form rows and fuse, thus becoming converted into fungus hyphæ. These hyphæ can then grow and infect wood which is sound and cause it to rot. Hartig called the fungus by the somewhat fanciful name of *Nyctomyces* (Nachtfaser), as an indication that the hyphæ originated in deepest darkness. Although Hartig shared the views of his time, and explained the presence of the fungus mycelium by spontaneous generation, he discovered facts which made him hesitate in this conclusion. Having observed the fruit-body of a Polyporus upon the outside of a rotten tree in which he could make out the *Nyctomyces* hyphæ, he asked himself the question whether the fruit-body had not been produced by the *Nyctomyces*. He failed to find the connecting hyphæ, the presence of which, he said, would entirely alter his views upon the origin of the *Nyctomyces*. Hartig's work, however, was of considerable value, for it added to our knowledge the fact that the decay of wood is usually connected with the presence of fungus hyphæ.

The origin of the hyphæ in decaying wood from spores produced by fruit-bodies became clear from the researches of de Bary, Tulasne, and others, upon plant-diseases.

Schlacht[1] investigated the changes brought about by fungi in dead plant-cells. He observed the disappearance of starch, protoplasm, and cell-walls, and paid particular attention to the passage of hyphæ through cell-walls and to their corrosion. Owing to the absence of fruit-bodies Schlacht failed to identify the fungi which he saw.

In 1866, Willkomm, in his *Microscopische Feinde des Waldes*, gave an account of some investigations upon Red Rot and White Rot. He observed different kinds of hyphæ in rotting

[1] Hermann Schlacht, *Jahrbücher f. wiss. Bot.* 1863, Bd. 3, p. 442.

wood, but failed to connect them with the fruit-bodies of Basidiomycetes. He added little that was new concerning the decay of wood. It is evident that the phenomenon was still very incompletely understood.

In 1878 appeared Robert Hartig's[1] work called *Zersetzungserscheinungen des Holzes*. It was provided with many excellent illustrations, and threw a flood of light upon the decay of wood. The fungi concerned and their method of action were described in detail. The account included *Trametes radiciperda*, *T. pini*, *Polyporus fulvus* (*Hartigii*), *P. vaporarius*, *P. mollis*, *P. borealis*, and *Agaricus melleus* upon the Coniferæ, and *Hydnum diversidens*, *Thelephora perdix* (*Stereum frustulosum*), *Polyporus sulphureus*, *P. igniarius*, *P. dryadeus*, and *Stereum hirsutum* upon the Oak. Hartig showed that each fungus has a specific action upon wood, so that it is often possible by macroscopic inspection of a piece of rotten wood to determine the species of fungus concerned in its decay, even in the absence of fruit-bodies. Great attention was paid to the corrosion of cell-walls and their dissolution. The disappearance of starch-grains and protoplasm was observed. Chemical analyses showed that, as wood decays, in many cases it becomes relatively richer in carbon. It was found that some fungi, such as the Dry Rot Fungus, remove the cellulose from the cell-walls, leaving behind a skeleton of friable wood-gum, whilst others, e.g. *Stereum hirsutum*, delignify and decolorise the lignified membranes so that the cell-walls come to respond readily to the microchemical reactions for pure cellulose. From these and many other observations it became clear that the chemistry of wood decay differs much with the different species of fungi concerned.

Several other publications of Hartig[2] were more or less devoted to the decay of wood. The chief is his monograph on *Merulius lacrimans*,[3] the so-called Dry Rot fungus of our houses. It may be pointed out that the term "Dry Rot" is a misnomer, for the fungus can only exist in damp timber, such as occurs in ill-ventilated cellars. Hartig showed that the fungus is able to creep some feet over brickwork, etc., from one beam or board to another, by developing curious strands containing specialised

[1] Berlin, 1878.

[2] *Wichtige Krankheiten der Waldbäumer*, Berlin, 1874; *Unters. aus d. Forstbot. Institut zu München*, 1883, Bd. 3; *Pflanzenkrankheiten*, Berlin, 1900.

[3] *Der ächte Hausschwamm* (*Merulius lacrimans*), Berlin, 1885.

conducting elements. The penetration of the hyphæ in the wood from tracheide to tracheide through tiny holes made in the walls was observed. Microchemical tests were found to indicate that juices excreted by the fungus bring about the removal of the cellulose from the wood cell-walls. With this chemical change is associated the mechanical weakening of the rotting woodwork. An account was given of the structure of the well-known fruit-bodies, and germination of the spores was described for the first time. Much of Hartig's work was devoted directly to the economic aspect of Dry Rot, and his book contains a number of suggestions upon the best means of protecting house-timber from the ravages of the fungus.

Marshall Ward[1] wrote a note upon "Penicillium as a wood-destroying Fungus." In a paper "On the Biology of *Stereum hirsutum*" he[2] described pure cultures of the fungus from the spore to the fruit-body, and gave an account of the changes it produces in wood.

A pure culture of a wood-destroying fungus, *Collybia velutipes*, was made by Constantin and Matruchot,[3] and later also by Biffen.[4] In a more recent paper by Falck,[5] a description with photographs is given of pure cultures of *Collybia velutipes*, *Hypholoma fasciculare* and *Phlœbia merismoides*. The fruit-bodies were grown from oidia, which were produced by the breaking up of the mycelium grown in pure cultures from spores.

In a paper "On the Biology of *Bulgaria polymorpha*, Wett," Biffen[6] has described the delignification of the cell-walls and removal of the middle lamellæ from the wood of the Oak by the fungus.

Czapek[7] has made an important contribution to our knowledge of the enzymes of wood-destroying fungi. He has extracted an enzyme from *Merulius lacrimans*, which he states brings about the delignification of the wood. He regards a lignified cell-wall as consisting, in part at least, of an ester of cellulose and hadromal,[8] which can be split up into its con-

[1] Marshall Ward, *Ann. of Botany*, 1898, vol. 12.
[2] *Ibid.*, *Phil. Trans. Roy. Soc.* 1897, vol. 189.
[3] Constantin et Matruchot, *Compt. Rend.*, 1894, t. 119.
[4] Biffen, *Journ. Linn. Soc.*, 1899, vol. 34.
[5] Richard Falck, *Beitr. z. Biol. d. Pflanzen*, Cohn, 1902, Bd. 8.
[6] Biffen, *Ann. of Botany*, 1901, vol. 15.
[7] Czapek, *Ber. d. D. Bot. Gesell.*, 1899, Bd. 18.
[8] *Ibid.*, *Zeitschr. f. physiologische Chemie*, 1899, Bd. 27.

stituents by the enzyme which he has named *hadromase*. The cellulose set free can then be broken down by cytase. The chemistry of lignified cell-walls is still to a large extent a matter of conjecture. Only when it becomes more fully cleared up can we expect to understand many of the chemical changes taking place in rotting wood.

In America, von Schrenk[1] has published a number of papers upon the destruction of wood and the diseases of forest trees. His work is of practical as well as of scientific interest.

In 1905 the writer[2] gave an account of the destruction of wooden paving-blocks by *Lentinus lepideus*, Fr. Fig. 1 shows the relationship of the fungus hyphæ to the wood-cells.

The following is a summary of the conclusions arrived at:

1. The destruction of a large number of paving-blocks, made of pinewood, in the city of Birmingham, is being brought about by *Lentinus lepideus*, a fungus belonging to the Agaricini. Considerable repairs to the pavement are thereby necessitated.

2. Single blocks or small groups of blocks at intervals in the streets go completely rotten, so that one can break up the wood with the fingers. The streets affected become unduly bumpy. In wet weather puddles collect above places where rotten blocks are.

3. A number of rotting blocks, obtained from time to time from the streets, were placed in a large damp chamber. In the course of a few weeks fruit-bodies of *Lentinus lepideus* appeared upon them.

4. The spores remain unchanged in distilled water and tap-water, but germinate readily in Pasteur's Fluid and in beef-gelatine. They also germinate in decoctions of horsedung and of pinewood.

5. The pavement is probably infected by spores after the

[1] Hermann von Schrenk, U.S. Dep. of Agric., Veg. Phys. and Path., 1900, Bull. 25, "Some Diseases of New England Conifers"; *ibid.*, 1900, Bull. 21, "Two Diseases of Red Cedar"; Twelfth Ann. Rept. Missouri Bot. Gardens, 1902; *Journ. Western Soc. Engineers*, 1901; "Factors which cause the Decay of Wood," Contribution 19, Shaw School of Botany, St. Louis; "Fungus Diseases of Forest Trees," *Yearbook*, U.S. Dep. of Agric., 1900; U.S. Dep. of Agric., Plant Industry, Bull. 14, 1902, "The Decay of Timber and Methods of Preventing it"; *ibid.*, Bull. 32, 1903, "A Disease of the White Ash caused by *Polyporus fraxinophilus*"; *ibid.*, Bull. 36, 1903, "The Bluing and Red Rot of the Western Yellow Pine, etc."

[2] A. H. R. Buller, "The Destruction of Paving-Blocks by the Fungus *Lentinus lepideus*, Fr.," *Journ. of Economic Biology*, 1905, vol. i.

blocks have been laid down. The mycelium often grows from a rotten block to the neighbouring sound ones. No fruit-bodies are produced in the streets owing to the traffic.

6. The wood is rotted by *Lentinus lepideus* in very much the same manner as by *Merulius lacrimans* (the Dry Rot fungus). It

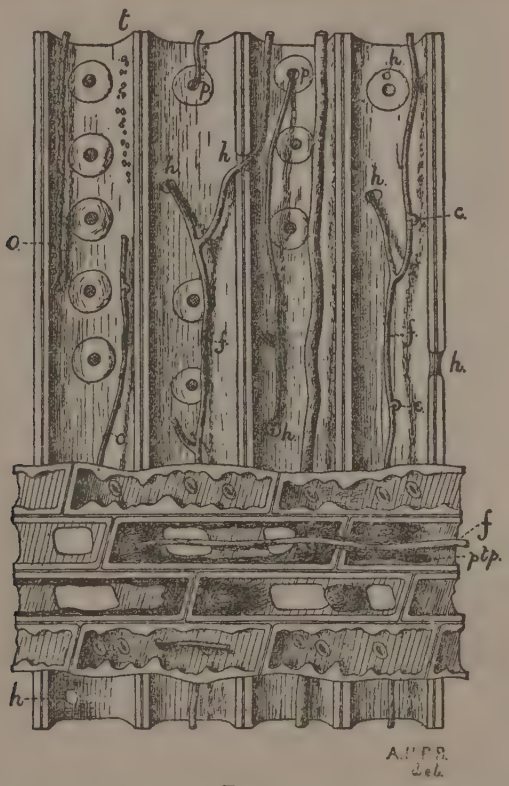

FIG. 1.

Mag. 450. Radial-longitudinal section of wood of Pine from a rotten paving-block. A medullary ray is represented crossing four tracheides. The hyphæ, *j*, of *Lentinus lepideus* are to be seen in the cell lumina. They are sometimes branched, and are provided with clamp connections, *c*. They make their way from cell to cell through bordered pits, *p*, or bore holes, *h*, through the walls. Some hyphæ are coated with crystals of calcium oxalate, *o*. At *t* the hypha has disappeared and a trail of crystals has been left behind. Cell contents, *ptp*, still remain in some of the medullary ray cells.

becomes red and spongy when wet; it shrinks and cracks considerably on drying, and is then very brittle and friable. Cellulose is removed from the cell-walls and hadromal left behind.

7. The paving-blocks, used in the pavements referred to, were dipped in creosote before use. Had they been fully impregnated with that substance, the ravages of *Lentinus lepideus* or any other wood-destroying fungus would have been prevented.

Much still remains to be done in elucidating the relationship of wood-destroying fungi to living trees. Some years ago Marshall Ward called attention to the fact that we knew practically nothing about *Polyporus squamosus*, one of the commonest Polyporei in England. The writer undertook to investigate its life-history, and in 1906 published a fully illustrated paper on "The Biology of *Polyporus squamosus*, Huds., a Timber-destroying Fungus."[1] A short account of the plant will now be given.

Polyporus squamosus, the Great Scaly Polyporus or Saddle-back Fungus, is one of the best known of the tree-destroying fungi. Its large ochraceous fruit-bodies, checkered with brown scales above, are frequently to be seen projecting as conspicuous brackets, either singly or in groups, from branches or the trunks of trees in woods, parks, and gardens. The fungus destroys a large number of ornamental trees, and has therefore excited the interest of many who have the care of them. It is not only common in Europe, but is also found in the United States. Whilst residing in Munich the writer had frequent opportunity of observing the fruit-bodies. In 1901 a series of fine old Horse Chestnuts and Sycamores were cut down in the Hof-garten owing to the majority having suffered from fungus attacks. In three cases fruit-bodies indicated the presence of *Polyporus squamosus*. During July 1901 four of the Red Chestnut trees in front of the Wittelbacher Palast were bearing fruit-bodies simultaneously. In the Englischer Garten two Wych Elms and an Ash were found in a similar condition. In England the fungus is equally common. Upon old trees in the suburbs of Birmingham it was seen on the Beech, Sycamore, Wych Elm, and *Pirus vestita*. The fungus was also noticed at Sutton Coldfield, Havant, Banbury, Oxford, and on the Elms in the Backs at Cambridge. *Polyporus squamosus* has never yet been found on Pine, Larch, or other Coniferæ. Otherwise it is not particular in its choice of hosts, for various authors record it upon the following trees: Sycamore, various species of Maple,

[1] A. H. R. Buller, *Journ. of Economic Botany*, 1906, vol. i. pp. 101-138.

Horse Chestnut, Pear, Mountain Ash, Oak, Elm, Ash, Willow, Birch, Lime, Walnut, and Hazel.

The fruit-bodies of *Polyporus squamosus* are the largest among British fungi. Few other species growing on trees form such conspicuous objects. During the summer of 1905 the writer gathered a perfect specimen 2 ft. 2 in. across, and having a perimeter of 6 ft. 3 in. It weighed approximately 6½ lb. As a rule, however, the fruit-bodies are not so large. Usually they occur several together, and the largest are then about a foot in diameter.

The fruit-bodies are annual. They are produced from May till September. In the Midlands of England they are especially abundant in July. If developing in warm, sunny weather, insects soon find them out, causing them to become infested

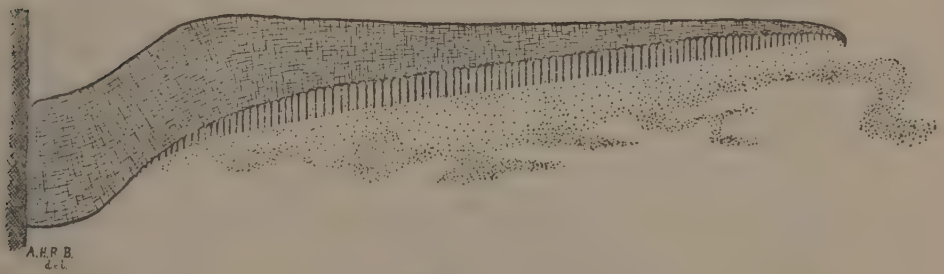

FIG. 2.

Mag. ½. Section through a fruit-body of *Polyporus squamosus* showing the hymenial tubes from which clouds of spores are falling.

with larvæ often before reaching maturity. They may thus become putrescent and fall within a few days or weeks after being formed. This is particularly the case with large specimens. A fruit-body is nothing more than an organ of reproduction. Its function is to produce, liberate, and entrust to the winds millions of microscopic spores. On the under side of a fruit-body of *P. squamosus* are developed some thousands of narrow hymenial tubes, which have their axes vertically placed and their mouths or pores freely opening below (Fig. 2). The spores are produced by the hymenium with which the tubes are lined. It was found that the spores are discharged with violence from their sterigmata. They are shot out horizontally to a distance of about 0·1 mm. They then make a sharp turn and fall vertically downwards in the tubes, without danger of

touching and adhering to the sides. They thus reach the open air in safety. Their rate of fall in still air was carefully measured, and found to be about 1 mm. per second. Spore-discharge lasts from five days to a fortnight. It is a continuous process, taking place night and day in dry and wet weather. The spores are produced in vast abundance. With a Leitz-Wetzlar counting apparatus it was calculated that each hymenial tube in one instance had produced nearly 2,000,000. The large fruit-body, already referred to, may well have given rise to 10,000,000,000. From another fruit-body the spores were liberated at the rate of about a million a minute.

Notwithstanding the activity of spore-discharge from the fruit-bodies of most Hymenomycetes, as a rule the falling spores cannot be seen with the naked eye. *Polyporus squamosus* proved to be a rare exception. The visibility of the discharge in this instance appears to be due partly to the great rate of spore-liberation from the large fruit-bodies and partly to the large size and colourless nature of the spores themselves. A fruit-body, some 10 in. across, was grown on a log in an experimental greenhouse where the air was very quiet. Under these conditions clouds of spores, resembling steam or the finest white smoke, were observed falling continuously for thirteen days. The wreaths and curls of spores drifted slowly away from the fruit-bodies, and became gradually lost at a distance of about two yards. Wreaths of spores were distinctly seen on a black background at a distance of 30 ft.

The fruit-bodies of some wood-destroying fungi—e.g. *Fomes igniarius*—are perennial. They are then very hard and of woody or corky consistency, and produce new hymenial tubes and spores each summer. They may continue their activity for ten or more years. On the other hand, the comparatively soft fruit-bodies of *Polyporus squamosus* are annual. They live but a few weeks altogether, and soon die after the spores have been discharged.

The spores of *Polyporus squamosus* are dispersed by the wind. As their rate of fall in still air is only about 1 mm. per second, it will be readily conceived that slight breezes are able to carry them very long distances before they settle. The chances of a spore falling upon a suitable wound surface of a tree, where germination and infection may take place, must be extraordinarily slight.

Polyporus squamosus is usually a wound parasite. Its spores in all probability germinate upon the wound surfaces of broken branches, where the mycelium can make its way directly into the wood. There is no evidence to show that an uninjured tree can become infected. The bark of trees appears to be fungus-proof. It entirely resists penetration of any germ-tubes from without. So far as the writer's experience has gone, fruit-bodies of the fungus are always to be found actually upon or near obvious wound surfaces, where the wood has been laid bare, so that germ-tubes could have made an entrance directly into it. As trees get older they become more and more liable to have wood surfaces exposed, owing to damage by wind, snow, lightning, frost, etc. The older trees become, therefore, the more likely they are to be infected by wood-destroying fungi. In parks and gardens, for various reasons, branches are frequently cut from Horse Chestnut trees, Sycamores, Beeches, etc., and thus admirable wound surfaces prepared by which *P. squamosus*, or any other wood-destroying fungus, may make its way into the trunk. The experience of the writer goes to show that in many cases infection has almost certainly taken place in this way, fruit-bodies having subsequently appeared on the wound surfaces. When branches are sawn off valuable ornamental trees, the exposed surfaces left ought to be at once creosoted or treated with some other antiseptic, to prevent the germination of spores. If this is not done there is always considerable risk that wood-destroying fungi will enter the trees and gradually cause their decay. When a mycelium has once established itself in a tree-trunk, it cannot be killed or its growth checked without injury to the tree itself.

When the mycelium of *Polyporus squamosus* has entered a large branch, guided by the wood cells, it makes its way gradually to the centre of the tree-trunk, and then spreads upwards and downwards in it, causing it to rot from within outwards. The fungus spreads slowly to the periphery, thus reducing every year the amount of sound wood. The conduction of water up the stem appears to be slowly interfered with. At any rate one notices a gradual dying away of the branches of an infected tree. Finally the whole tree may succumb, but, if it is large, its death is often long delayed. Fruit-bodies may appear annually for ten or more years upon an Elm or Sycamore, whilst it is still living. The wood, how-

ever, becomes more and more extensively rotted as time goes on, until at length an unusual storm may cause the trunk to snap in two. When a tree infected by *Polyporus squamosus* has died, the fungus can still continue its annual production of fruit-bodies. It is then a pure saprophyte. With the tree-destroying fungi, which live in the wood, there is usually no hard-and-fast line between parasitism and saprophytism.

FIG. 3.

Mag. 300. A fibre isolated by Schulze's maceration mixture from the rotten wood of a Sycamore. The holes in the cell-wall were made by the mycelium of *Polyporus squamosus*.

The mycelium of *Polyporus squamosus* makes its way into the cell-lumina of the infected wood. It does this by boring small holes in the lignified cell-walls. The ends of the hyphæ probably excrete an enzyme or enzymes capable of rendering soluble the hard membranes. Through holes thus made the fungus hyphæ readily pass from cell to cell. In course of time the least lignified cell-walls disappear entirely. The autumn wood, the medullary rays, and the vessels with the sheath of cells around them are the most lignified elements in Sycamore wood, and here they last longest, but become more and more riddled with holes (Fig. 3). At length the wood becomes reduced to a skeleton of its former self. The decay is known as White Rot, because the wood turns much lighter in colour under the action of the fungus. Starch, protoplasm, and cellulose are gradually removed. They are probably rendered soluble by means of appropriate enzymes. This view is supported by an investigation into the enzymes of the fruit-bodies.[1] The following were found to occur in the expressed juice: laccase, tyrosinase, amylase, emulsin, protease, lipase, rennetase, and "coagulase," whereas negative results were obtained in the tests for pectase, maltase, invertase, trehalase, and cytase. However, a study of the destruction of wood by the fungus affords evidence that the mycelium produces cytase and possibly hadromase. Altogether,

[1] A. H. R. Buller, "The Enzymes of *Polyporus squamosus*," *Ann. of Botany*, vol. 20, 1906, pp. 49-59.

therefore, the juice of the fruit-bodies appears to be able to bring about at least nine or ten different enzyme phenomena. There is every reason to believe that the destruction of wood by *Polyporus squamosus*, or in fact by any wood-destroying fungus, is chiefly due to the enzymes it is capable of producing.

The conditions for the germination of the spores of wood-destroying fungi still await a much fuller elucidation. In some cases, such as *Polystictus versicolor*, the spores germinate readily in water, and also on the surface of moist wooden blocks (*vide infra*). We can, therefore, easily understand with this species how infection of exposed wood takes place. On the other hand, the spores of *Lentinus lepideus* and *Polyporus squamosus*, although they germinate readily in various nutrient media, such as beef-gelatine, malt-extract, and Pasteur's Fluid, do not put out germ-tubes in water: nor in the last-named species will the spores germinate on fresh wound surfaces of branches kept moist in the laboratory. The conditions for the infection of trees by the spores of *Polyporus squamosus* in nature are therefore still unknown. It was thought that, if spores were placed on large fresh wounds of living trees, infection might take place. Two years ago six large and sound trees, Sycamore, Beech, Ash, Elm, Lime, and Horse Chestnut, were chosen. Six suitable wounds were made in each tree by sawing off large branches, etc., and the wound surfaces were carefully strewn with millions of some freshly-fallen spores. It was hoped that infection might result, but fruit-bodies as yet have failed to make their appearance upon the trees.

The latest paper on a wood-destroying fungus (1908) is that of Miss Bayliss on "The Biology of *Polystictus versicolor* (Fries)."[1] *P. versicolor* is one of the most familiar objects to the field mycologist, but its life-history and ecology had been neglected. Miss Bayliss found that its spores germinate in water, and that when they are placed on the outside of damp blocks of Ash, Elm, Bird-cherry, Alder, Sycamore, Horse Chestnut, and Birch, infection of the wood readily takes place. The mycelium, however, would not grow in pine- and larch-wood. The life-history of the fungus was traced from spore to spore. Fruit-bodies developed on the infected blocks in the course of a few months. It was shown that the mycelium of the fungus can retain its vitality in a dried stick for at least

[1] J. S. Bayliss, *Journ. of Economic Biology*, vol. 3, 1908, pp. 1–22.

four years. A number of interesting observations were made upon the development of the fruit-body. Zoning of the upper surface of the pileus seems chiefly due to an alternate checking or promotion of growth caused by changes in the amount of moisture in the atmosphere. Fruit-bodies of irregular shape, but nevertheless producing spores, were developed on a stick which was rotated on a klinostat for four months. It was proved that light is necessary for the development of the hymenium, but that the form and position of the fruit-bodies are determined by geotropic stimuli. The dried spores were found to retain their vitality for eleven weeks.

The writer will shortly publish his researches[1] on the production, liberation, and dispersal of the spores of Hymenomycetes. The fruit-bodies of the wood-destroying fungi, regarded as spore-producing organs, will be dealt with in some detail. Among other points evidence will be brought forward to show that the fruit-bodies of Polystictus, Stereum, Lenzites, and other leathery or corky species found on wood are xerophytic. On desiccation they retain their vitality for months, or in some cases years. With access to moisture they completely recover and shed vast numbers of spores.

The question of preventing the decay of timber is one of great economic importance, and has long attracted attention in this country. According to Boulton,[2] already "by the year 1838 four several systems of antiseptic treatment were fairly before the public and competing for the favour of engineers. These were corrosive sublimate, sulphate of copper, chloride of zinc, and heavy oil of tar." Soon after their formation the railway companies found themselves obliged to protect the sleepers from decay, and hence they have been very active in making extended experiments and observations on timber preservation. Long experience has now proved beyond a doubt that there are certain salts and substances which, when injected into wood, prevent its decay, and so greatly lengthen its period of usefulness. It is also certain that antiseptic treatment pays. The chief question of importance at the present day is that of deciding which of the various processes known can be used to greatest advantage for railway sleepers, fence posts, bridge

[1] *Researches on Hymenomycetes*, Longmans, Green & Co.

[2] S. B. Boulton, "On the Antiseptic Treatment of Timber," *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 78, 1884, p. 102.

timbers, telegraph and telephone poles, and, indeed, structural timbers of all kinds.

A few years ago the United States Department of Agriculture commissioned Hermann von Schrenk to visit Europe for the purpose of studying the various processes employed for timber impregnation. The results of von Schrenk's investigations are embodied in an elaborate report, called "Decay of Timber and Methods of Preventing it."[1] According to this report (in which railway sleepers are more especially dealt with), in England, Belgium, and France the creosoting process is the one chiefly used. Although it is the most costly, it is found to pay best in the end in these countries. In Germany and Austria a cheaper process, making use of zinc chloride and tar oil, is now employed, whilst in some other lands the still cheaper zinc chloride process finds favour. In England and France engineers believe that their system gives the best results, and they use as much of the impregnating material as the timber will hold. The extra first cost of the sleepers is amply paid for, as their life is increased by many years. Creosoted pinewood sleepers, in some cases, have lasted twenty-five years or more. Timber wholly impregnated with creosote never rots, but may be worn out by mechanical abrasion. The advantage of using zinc chloride and coal tar in conjunction is supposed to be that the coal tar prevents the leaching out of the zinc chloride. When the latter is used by itself, it disappears from the sleepers in course of time.

About ten years ago a process of wood preservation known as the Hasselman treatment[2] was developed. Salts injected into wood are soluble in water, and hence liable to leach out. The Hasselman treatment is supposed to cause the injected salts to form an insoluble compound with the wood cell-walls. The timber to be treated is put into a closed cylinder, and a solution of copper sulphate, iron sulphate, aluminium sulphate, and a small amount of kainit is run in. By means of superheated steam the solution is brought to boiling-point. The timber is boiled in the solution for several hours. The advantages of the process lie in the cheapness of the salts employed, the rapidity of the process, the fact that the wood to be treated may be wet or dry, and also that the iron and copper salts penetrate every fibre of the wood and form insoluble compounds with the wood

[1] U.S. Department of Agriculture, Bureau of Plant Industry, Bull. No. 14, 1902.

[2] H. von Schrenk, *loc. cit.* p. 55.

substance. The first experiments with the process were made by the Bavarian Government, but since that time a number of private companies have used this method of treatment.

Certain newer methods of timber impregnation, such as (1) the senilisation process, (2) the emulsion treatment, (3) the creo-resinate process, and (4) the Ferrell process, were found by von Schrenk in 1902 to be still undergoing trial. In the senilisation process, which is used by a French company, the wood is impregnated with magnesium sulphate by means of an electric current. The emulsion treatment is an attempt to reduce the amount of the tar oil required. One of the methods of doing this is to employ an emulsion of tar oil made by dissolving various quantities of resin in the tar oil and adding a strong solution of soda lye (NaHO). In the resulting emulsion the tar oil is found in the form of exceedingly minute drops, which remain in the emulsified state for several weeks. The emulsion, when pressed into wood, distributes the tar oil evenly throughout its outer layers. The creo-resinate process is like the emulsion treatment, but instead of adding lye the inventor adds formaldehyde. The wood is first subjected to a high degree of heat, to kill any organisms present in it. After creating a vacuum the impregnating solution is run in. The process is supposed to render the wood absolutely sterile at first, and then to give it additional protection outside. The Ferrell process is of American origin. The inventors state that they can inject various salts, such as aluminium sulphate, sodium chloride, calcium chloride, etc., into timber through its ends. They say that the salts penetrate all the fibres thoroughly, and that they can cause the union of two salts in the wood, forming insoluble compounds.[1]

[1] For literature upon timber decay and impregnation, *vide* the bibliography to von Schrenk's Report.